Radiology Systems of the 1990s—Meeting the Challenge of Change

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Digital imaging technology, particularly reconstructed images such as computed tomography and magnetic resonance imaging, has fueled the increased demand for radiologic services but has intensified storage and communications problems. Today more than 25% of radiologic examinations are digital in origin and, with progressive replacing of film images by digital images likely through the introduction of imaging plate technology, the radiology profession is undertaking the massive effort of evolving a new system where digital images will be transmitted, stored, retrieved and displayed by a multicomponent system connected by a local area network. Through this system, images will be nearly instantly accessible to anyone who needs them.

A leading hypothesis is that when the volume of digital examinations reaches 50% of the whole, cost and efficiency considerations will lead to a massive conversion to the digital image management system, which will progress spontaneously. This conversion, unless planned for in today's equipment acquisitions, could lead to great economic stress in hospitals. The 50% point may be reached by the early 1990s.

(Lodwick GS: Radiology systems of the 1990s—Meeting the challenge of change, *In* Medical informatics [Special Issue]. West J Med 1986 Dec; 145:848-852)

In the past 30 years, the field of radiology has changed from a narrow discipline located in the basement of hospitals to a dynamic set of interrelated specialties functioning at the heart of medical practice. This change is related to the broadening of the scientific base of radiology. Foremost has been the revolutionary improvement in image quality and the speed with which image information can be captured. New contrast agents and selective catheterization have allowed the dynamic imaging of vascular organs; new nuclear tracers provide highly sensitive imaging technologies for detecting disease. Radiologists now take biopsies of tumors and drain abscesses. A truly fundamental advance is the computed reconstruction of images, which has brought digital imaging into the clinical environment. Radiology is now more than a medical discipline; it includes physicists, engineers, computer scientists, radiobiologists and physicians who are the best that our medical schools have to offer. And given the organizational and interdisciplinary complexity of the modern radiologic sciences department, computer-based communications systems are vital to effective functioning.

With the introduction of computed tomography (CT), there is a trend to replace the existing film imaging with digital images. This trend is accelerating to the point where 25% or more of the daily production is digital.[1] While most such digital images are of relatively low information density—512 by 512 pixels by 8 bits or less—a new imaging technology that uses a solid-state plate and laser scanning for providing high-resolution digital images promises to sharply increase the volume of digital image production. Using this technology, it becomes possible to produce images of high informational content, such as of chest and bone, on high-resolution 2,048 by 2,048 pixel monochrome displays ("Manipulating Digital X-rays Enhances Different Features," *Electronics*, Feb 3, 1986, pp 39-41). Given the volume of image production in a busy department, if all images were digital, the amount of new digital information that would need to be stored, transmitted and displayed is more than 4 gigabytes per inpatient bed per year.[2] In fact, each patient's images need to be displayed as many as ten times during the first week of hospital admission.[3] Realistically, we are only beginning to understand the requirements for the systems that comprise a picture archiving and communication system (PACS), and, for this reason, we are not yet ready to implement a radiology information system that can handle this volume.

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ABBREVIATIONS USED IN TEXT

ACR = American College of Radiology
CT = computed tomography
MARS = Missouri Automated Radiology System
NEMA = National Electrical Manufacturers Association
PACS = picture archiving and communication system
RIS = radiology information system

With the volume and proportion of digital images growing steadily without an adequate system for digital image management (PACS) , the pressure is on to identify all of the problem areas and to resolve the issues that surround digital image management. In the meantime, the profession is obliged to compromise by recording digital images on film. Managing film images has long been a thorny problem because all who care for a patient both want and need to see the images at the same time. In a department with poor control of the film library, this demand creates a chaotic situation in which film images are lost or stolen, followed by a sequence of events that tends to delay and, at worst, cripples the process of taking care of a patient.[4] If we could but reverse this trend to provide digital storage and display of all images, then it would be technologically possible for all physicians to see the same images at the same time, and the single most difficult problem in radiology would be resolved.

The Radiology Information Management System

The problem of the film library is not a new one; it just has become less manageable with increased volume and demand. By 1966, with a growing accessibility of computers, new systems for implementing solutions to scheduling, filing, reporting and billing began to appear.[5-10] At first, each system seemed to provide its own unique approach to resolving the radiology management problem; some were oriented to methods of getting a consultation reported in a timely fashion, others to getting the bills out. With the passage of time, it became apparent that certain solutions were better than others and that some innovations were obviously desirable, so that most systems came to have certain features in common. The system with which I was associated, the Missouri Automated Radiology System (MARS), went on line at the University of Missouri-Columbia School of Medicine (Columbia, Mo) in April of 1970[11] and underwent constant modification until it became an extremely useful system. In 1974 the cost-effectiveness of MARS was the subject of a detailed economic analysis,[12] following which the hospital assumed financial support of the system. A major element of the continuing success of MARS was that the MUMPS programming language permitted on-line modification without interrupting function. Hence, MARS was kept up-to-date.[13] For all systems, a rapid turnaround of reports was the problem least easily resolved[14-17] and often is a problem today. For film tracking, Bauman's use of bar coding has proved successful.[18]

It is a truism that a well-designed and supported radiology information system (RIS) becomes an instrument of management policy. It is equally true that, to be successful, a RIS must have the support of the chief of the department of radiology and, in a hospital, of the director of the hospital. A personal anecdote provides an interesting reflection on the value of a RIS. After more than 20 years as Chair of the Department of Radiology at the University of Missouri, I decided that I had achieved about all that I could as manager and retired to research and writing. My successor apparently ran into some of the insoluble issues that had plagued me during my tenure and ultimately gave it up. Not without some concessions by the dean and the University Hospital, I took on the responsibility again and was quite pleased to find that within a week it was possible to generate five-year charts showing patient volume, mix, financial trends and time flow—in short, all the information necessary to resume planning for the department's future. In my absence, the computer had been quietly ticking along, "faithfully" collecting all of this information that simply awaited analysis. I do not see how a large department can be managed effectively without an RIS. James Lehr, MD, who has redesigned MARS for the University of Chicago's Pritzker School of Medicine,[19] has written comprehensively on RISs.[20] The formation of the RIS Computer Consortium[21] has led to a systematic implementation of DECRAD, a state-of-the-art information system, which is being widely implemented. Many other RISs are now being marketed.

The Radiology Image Information System

With the flow of digital images into the clinical environment having been initiated and with the success of RIS as a model, we began to examine the possibility of implementing an image information managing system.[22] By 1977 digital image management had become enough of a problem that Hill and Jost were implementing data compression for more efficient archiving of CT findings.[23] A major stimulus to giving serious consideration to such digital systems has been the promise of mass storage devices for archiving digital data, particularly the digital optical disc. This festering problem of storing voluminous digital image files without systematic access added a sense of urgency to planning and implementing the new image management system. Implementation has been slow for many reasons, however, a major one being that industry is still not geared to the task of producing a system for storing, retrieving, transmitting and displaying digitally acquired radiographic images within the constraints of speed, spatial resolution and human engineering imposed by the radiologist users. At the same time, radiologists have not had hard data to answer many questions related to the design specifications of the proposed system. Many questions will eventually be resolved by research with human subjects, some others by trial and error and all ultimately by the marketplace.

The design and implementation of an image information management system is a massive scientific effort, the successful implementing of which will have an impact far beyond the perimeters of radiology. Accordingly, as a systems problem, it will not be rapidly resolved, but, rather, success will in large measure depend on simultaneously solving tough technical problems now under intensive study. Many of these are beyond the normal expertise of radiologists, while others can be solved only with the professional guidance and collaboration of radiologists. A number of recently published review articles have illuminated the technical scope of the image management system and the progress that has been made.[24-26] Several problem areas are briefly discussed below.

The Financial Atmosphere

The desire to contain costs and the change in methods of reimbursing a radiology department to charging costs against a total predetermined by federally imposed diagnosis-related groups has placed us in the position of needing to design a system that diminishes operating costs. The economics of PACS has been examined,[27,28] but as yet we do not have a good enough model to show that PACS can compete economically with current film systems. We have not been able to afford to implement those models of systems that incur major costs for displays. As of now, several systems for creating digital x-ray images are being extensively tested in Japan, based on the Fuji technology, which acquires images digitally from plates but captures the digital information on film. This technology permits bypassing the costs of digital storage, networking and displays. Such systems are only one component of the image management system but can be plugged into an existing department without requiring a major change in a radiologist's routine and possibly without major change in operations or costs. While these systems tend to perpetuate film-based departments, they will satisfy the radiologists' traditional demand for film images. The Fuji plate technology represents a technologic breakthrough for generating high-resolution digital images and undoubtedly will accelerate the conversion to the digital department.

The ACR-NEMA Digital Interface Communications Standard

The design specifications of most digital imaging equipment do not include standardized output signals. The result of this is that if image signals are to be transmitted on a network or displayed on another manufacturer's equipment, a special interface must be designed to make the original image signal interpretable. In a major departure from the past, the users of radiologic imaging equipment, represented by the American College of Radiology (ACR), and the manufacturers of imaging equipment, represented by the National Electrical Manufacturers Association (NEMA), have formed a joint committee, with its first task to specify a standard interface for the transfer of digitally formatted images. In just two years this committee and its working groups have created an industry standard interface, ACR-NEMA Digital Imaging and Communications Standard, publication No. 300-1985, available from the National Electrical Manufacturers Association, 2101 L St NW, Suite 300, Washington, DC 20037. The interface specifies the lower four layers of the ISO-OSI seven-layer reference model.[29] The standard specifies a 16-bit parallel interface with six control signals. Data rates of 8 megabytes can be achieved over a cable of 15 m maximum length. The standard is now being implemented by various manufacturers and other interested parties. Working Group 4 of the ACR-NEMA Committee will shortly present its recommendations for a tape interface standard, and approval is expected by the end of 1986. Under study are plans for accommodating various compression algorithms with the interface standard and for transmitting three-dimensional images through the standard interface. Working Group 6 serves to help validate the standard. The ACR-NEMA Committee will continue its function for the foreseeable future, upgrading the standards as required. A comprehensive analysis of the interface standard is being prepared for publication in 1986.[30]

The Digital Workplace

Of all of the elements of a digital image management system, the display is perceived as most problematic. This is because it must be designed to replace not just a set of illuminated view boxes but rather a complex system for efficiently presenting a preprogrammed day of work for radiologists, with as many images as necessary for thoroughly understanding each case. The rule is that the display must function at least as well as radiologists' present equipment or it will not be acceptable. Radiologists must be able to interrupt their examination of specific cases, look at images of immediate interest to referring physicians and easily resume their scanning of those cases. Images that are upside down or backward must be repositioned. Images must move rapidly and with precision: it must be possible to reposition images in closely aligned groups for ease of comparison. It should be possible to window CT scans or to call up images from another examination for comparison. The display must be a facile window into the image file of the institution. It must be possible to simultaneously review previous reports on a case under study or to annotate examinations where desirable. It should be possible to accomplish all of these maneuvers at a display screen time of 0.5 seconds or at a rate comparable to moving films by hand. And there should be the possibility of obtaining hard copies on film or paper.

The largest and most elaborate displays will need to present images at 2,048 by 2,048 squared pixels with 12 bits of grey-scale depth. Dwyer believes that a single display screen may suffice[25]—a debatable issue. Less elaborate displays may have less spatial resolution but can accommodate by reviewing smaller areas of images of higher pixel densities and through zooming. So far, displays that fully meet the needs of radiology have not yet been marketed, and the prototype models have been prohibitively expensive. A generic display with the features of a high-level work center, versatility and more is under development in the radiology department at Massachusetts General Hospital (R-Star). Many others are also under development.

Data Compression

Given the high data rates and the huge storage capacities required for archiving and rapid transfer of digital images, methods for reducing data volume are of great interest. Each digital image contains information that is redundant in that it does not contribute to the diagnostic content of the image. Some images contain a great deal more redundant information than others. Contrast level redundancy refers to patterns of repetition in the degree of pixel brightness. Huffman encoding is a commonly used method of providing contrast compression through estimating the probability of occurrence of pixel contrast values.[31] "Lossless" encoding permits image data compression that is not subject to loss of information. The amount of image compression that can be achieved without loss of information, however, is relatively small, such as 2:1 or 3:1. Other compression techniques extend to 20:1 or higher, but with nonrecoverable loss of image information. Image decompression times are also a significant issue because the time required for decompression may be many times longer than that required for the initial compression.

At this point, if images can be compressed at high rates without losing diagnostic quality, this would make the image transmission, archiving and retrieval times much faster and less expensive. Because of this economy, image data compression has become a very important issue but one that can only be finally solved by experimentally determining which algorithms can provide the greatest time and cost benefits without significantly degrading diagnostic quality.

The Local Area Network

Computer networks are an essential part of the digital image management system. The twisted wire networks are far from fast enough for image transmission purposes, and coaxial cable provides a marginal top signaling rate of 60 megabits per second.[25] It seems very likely that future transmission needs will be met only through the use of fiber-optic cables, which will provide a signaling rate of more than 200 megabits per second. While few departments are now using networks for image transmission, many are installing cables, often both coaxial and fiber-optic cables.

It should be noted that the data-signaling rate is much higher than the actual rate of data production, the difference being due to overhead such as the size of records being transmitted, the size of buffers and the number of active nodes on the network.[25] Obviously, image data compression is an extremely important variable in improving the data-production rate of PACS networks.

Archiving and Data-Base Management

In radiology departments today, digital images are stored on magnetic tapes and discs, usually in files that often are remote from the active department. Film copies of digital images, such as CT, magnetic resonance images and ultrasonograms, are filed in a master folder in the film library. If the film copies of CT images are lost, the magnetic media are withdrawn from storage and are scheduled into the patient queue for access to the CT scanner, where they are rephotographed. This process takes 24 hours or longer under any but urgent circumstances. Archiving of digital images on mass storage media such as optical disc or tape storage clearly is desirable, but for mass storage to exist, there must be mechanisms and demands for accessing mass storage. There must be data transmission networks, imaging devices that feed the transmission networks and workstations for accessing and displaying the digital images that are filed in mass storage. We have a chicken-and-the-egg situation; you cannot have a part without the whole. These systems are generally not available except as prototypes. Noz and co-workers recently surveyed PACS systems, mostly in universities and in large hospitals, to find that some prototype systems are centralized and others decentralized.[24] In a centralized system, every image that goes onto the network gets sent to the image archiver or file server. All requests also go through the central archive. The decentralized system may have local magnetic disc archives and a ring or star configuration, so that images and messages can be sent directly to other points on the network without going through a central archive. Raytel markets a PACS that offers two digital optical disc archives featuring multiplayer laser optical disc "jukeboxes." These disc stores have a four-second response time to search, load and spin to an image. The PACS offered by Raytel is based on a centralized topology. Generally, however, massive storage is still a part of the prototype development that is now going on. Data-base management systems are a part of this development.

Discussion

Those who have been participating in the development of the radiology image management system can see that all of the parts of the system are inevitably being assembled. The question is when they will all be put together and start being used as a system. We can see that this is happening in a limited way now, largely in university settings using manufacturers' prototypes. The manufacturers of imaging equipment have assembled PACS research and development teams and are looking at the marketplace, measuring radiologists' enthusiasm, seeking opinions from the experts and hedging their bets on the future. A PACS is big money. A well-informed guess is that the image information systems will move off center and gain momentum when the proportion of digital images to film images reaches 50%. As of 1984, the evidence is that the volume of digital imaging at Massachusetts General Hospital was 20% of the whole and that plain film images comprised the remaining 80%.[2] This would indicate that 30% of film images would need to be converted to digital format before the system would begin to take off.

As of now, the major viable large-volume source of high-resolution digital images that would replace standard x-ray film images would appear to be from the clones of the Fuji imaging plate system now being produced in Japan and Europe. If this proposed algorithm of 50% replacement is correct, we will know when the time has come by watching the sales of imaging plate technology. Money must be available, however, for the larger health care institutions to buy such technology, which means that there will need to be enough savings to make these systems attractive. Given this scenario, it can be anticipated that we will be well into the 1990s before operational image management systems are a significant factor in improving the quality of radiologic practice. In the meantime, the component systems will be polished and, with current trends, the prices will diminish.

Conclusions

After nearly 20 years of development, radiology information systems are now routinely used in large departments. Still incompletely resolved is the reporting function, where the equivalent of direct dictation and transcription is desirable. Voice recognition has been tested but not yet proved sufficiently reliable.[32] Coded reports, direct entry by radiologists, telephone access to dictated reports and tightly coupled transcription pools are all solutions that await a better one.

What is to be the future of the RIS in the presence of the PACS system? RIS covers a broad spectrum of functions that support but are not a direct part of image management. Lehr believes that the implementation of PACS should probably be considered as a replacement of the film-file-management module of an RIS.[33] PACS could not survive in an environment without the RIS function. The evolution of PACS will inevitably include the fusion of the two systems.

The future implementation of PACS appears to depend on establishing in radiology departments a cost-effective digital replacement of the standard x-ray image. It can be predicted that radiologists will give up film images with great reluctance. For this reason the systems that are based on the Fuji imaging plate principle, producing either a digital x-ray film or, alternatively, an image on a high-resolution screen, appear to be the most viable candidates for replacing the standard x-ray image.

Economics will remain a major issue. If the imaging system can be shown to speed the process of inpatient care, save money through providing efficiencies in film production and management and, particularly, if systems are interfaced with hospital systems and inform hospital administrators as to how radiologic resources are used, then money will be found to support their purchase. It is not so much whether society can afford information management systems as whether it can afford not to have them.

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